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Method for qualification of telephone lines

The invention relates to a method for detection of impedances, in particular serial inductances, in telephone lines with two metal wires as signal conductors, for qualification of telephone lines with two metal wires as signal conductors (twisted pair) for suitability for data transmissions based on the DSL Standard according to the precharacterizing clause of Claim 1, and to the use of a DSL modem for carrying out a method such as this.

In modern data transmission, which is used increasingly frequently and over ever larger areas, via conventional metallic telephone lines with two line cores (which are generally formed from copper wires), one problem that arises is that these lines, which were often laid decades ago, were not designed for transmission frequencies above 6 kHz.

Particularly in rural areas and in particular in the American area, lines have often been laid which were provided with so-called "load coils" in order to improve the transmission of frequencies in the range from 1 to 5 kHz. These are series inductances which were looped in pairs into the two line cores - provided with a common toroidal core - at regular intervals, for example with 66 mH in each case at intervals of 900 meters, or with 88 mH in each case at intervals of 1.2 km.

However, transmission frequencies above 5 kHz, in the range from several 10 to 100 kHz, must be possible for data transmission.

This is impossible in the presence of impedances, in

particular the inductances which have been mentioned, whose purpose was to reduce the attenuation in the speech band, since they represent an excessively high impedance for high frequencies.

Since there are often no accurate records relating to the type of lines, or to whether inductances were or were not laid, the line must be qualified before it can be used for data transmission.

This is expensive and highly time-consuming, particularly when telephone company employees have to be sent out in order to measure the line.

US 5,465,287 and US 4,620,069 disclose methods for determination of line impedances, which are preferably carried out in digital switching centers for telephone networks. Further evaluation methods for determination of pole position and zero position frequency information, which make it possible to deduce that there are inductances on two-wire telephone lines, are described in US 4,229,626 and US 4,307,267. The methods according to the prior art have the primary disadvantage that it is either necessary to obtain complex additional devices, or the qualification of the respective telephone line cannot easily be carried out by the subscriber himself.

The object of the invention is to provide a method in which any impedances for qualification of a conventional telephone line can be detected at as low a cost as possible and with a high degree of reliability.

This object is achieved by a method for qualification of telephone lines according to Claim 1, and by use of a DSL modem according to Claim 11 and according to

Claim 12.

The invention provides a method for detection of impedances, in particular along inductances (looped-in in series), in telephone lines with two metal wires as signal conductors in order to qualify them for their suitability for data transmission at frequencies above the speech band, having the following steps:

(a) a test signal in the form of an AC voltage is fed into the telephone line,

(b) a reflection signal of the test signal is measured, which can be tapped off as the component, reflected on the input impedance of the entire line, of the test signal fed in at the start of the line,

(c) the first two method steps (a) and (b) are carried out at a number of different frequencies within a preselected frequency range of the AC voltage of the test signal in order to measure any phase shift in the reflection signal with respect to the test signal at the respective frequency,

(d) the phase shift is analyzed as a function of the frequency in order to assess the telephone line, in which case:

  the derivative of the phase shift is formed on the basis of the frequency,

  - the second derivative of the phase shift is formed,
  - the second derivative of the phase shift is investigated for one or more mathematical sign changes, and

  in which case

  - when a mathematical sign change occurs in the second derivative of the phase shift, the telephone line is assessed as not being suitable for use for data transmission at frequencies above the speech band, without further technical

actions.

The invention proposes that an AC voltage signal be fed in, which is, of course, partially reflected on the overall input impedance of the line. This reflected signal is then investigated for its line resistance. The phase shift is recorded as a measurement signal of the reflection signal with respect to the test signal. Investigation of the profile of the second derivative results in clear information as to whether there is any impedance in the line. This represents a considerable simplification in comparison to previous measurement methods, having a number of test steps which have to be carried out individually and manually.

This is used for qualification of telephone lines of the type with two metal wires as signal conductors (twisted pair) for suitability for data transmissions based on the DSL Standard. When there is a mathematical sign change in a second derivative of the phase difference between the measurement signal and the test signal over the frequency in a preselected frequency range, the line is assessed as not being suitable for use for data transmissions based on the DSL Standard, without further technical actions.

One preferred method step provides for the AC voltage to be a sinusoidal AC voltage. A sinusoidal AC voltage such as this can be generated and detected easily on a DSL modem card.

According to one advantageous refinement of the method, the phase shift is determined by means of a phase discriminator.

According to one refinement of the invention, which is

likewise advantageous, the phase shift is determined by means of a quadrature demodulator.

One advantageous method step provides for the frequencies to be chosen to be between 1 and 5 kHz, in particular with regular or logarithmic intervals between the individual frequencies. The so-called load coils can be detected particularly well, especially in this frequency range.

One particularly advantageous and thus preferred method step provides that, before the second derivative of the profile of the measurement signals based on the frequency is formed, the individual measurement signals are averaged in order to smooth them in the profile. The smoothing is used to reduce the "noise components" (which are statistically independent with respect to the actual profile), and improves the capability to evaluate the data.

In consequence, median formation is carried out as the smoothing process according to one refinement of the invention.

One advantageous refinement of the method provides that, in a step which follows the median formation, individual smoothed measurement signals, which are at a regular interval from one another, are supplied for further evaluation. This leads to data reduction, which simplifies the evaluation process, and which does not result in any corruption of the results, owing to the previous smoothing of the data.

A further aspect of the invention provides for use of a DSL modem for carrying out the method as described above, using the data driver and receiving module which

is provided in the DSL modem that is used. This makes it possible to use already existing hardware in a particularly simple manner, without any need for further developments.

Furthermore, the invention proposes the use of a DSL modem at the network provider end for carrying out the method mentioned above, in which case the test module which is present in the DSL modem that is used at the switching center end is used, which is often provided in a DSL modem at the network operator end, in order to make it possible to pass analog currents and/or voltages of different types to the line, and to measure them, in order to make it possible to carry out an electrical test on the line in this way. In this case as well, the advantages result from the use of already available hardware.

Further advantages, special features and expedient developments of the invention result from the further dependent claims or from sub-combinations of them.

The invention will be explained in more detail in the following text with reference to the drawing, in which:

Figure 1 shows a detail of a telephone line with load coils,

Figure 2 shows an equivalent circuit of the line for low frequencies,

Figure 3 shows an equivalent circuit of the entire line with load coils for low frequencies,

Figure 4 shows the qualitative profile of the characteristic impedance Z as a function of the frequency,

Figure 5 shows the overall input impedance of the line plotted against the frequency,

Figure 6 shows the real part of the input impedance of the line plotted against the frequency,

Figure 7 shows the imaginary part of the input impedance of the line plotted against the frequency,

Figure 8 shows the phase shift of the input impedance of the line plotted against the frequency,

Figure 9 shows the first derivative of the phase shift of the input impedance as a function of the frequency for different constraints,

Figure 10 shows the second derivative of the phase shift of the input impedance as a function of the frequency for different constraints,

Figure 11 shows a flowchart of the method,

Figure 12 shows a measurement example of a measured and calculated first derivative,

Figure 13 shows a measurement example of a measured and calculated first derivative after averaging for smoothing,

Figure 14 shows a measurement example of a measured and calculated first derivative after data reduction has been carried out,

Figure 15 shows a measurement example of a calculated second derivative,

Figure 16 shows a schematic illustration of assemblies of a DSL modem,

Figure 17 shows a schematic illustration of those assemblies of the DSL modem which are involved in the evaluation process,

Figure 18 shows a module which is involved in the analysis based on a first example,

Figure 19 shows a module which is involved in the analysis based on a second example,

Figure 20 shows a schematic illustration of the DSL modem assemblies which are involved in the evaluation process for phase difference

measurement, and

Figure 21 shows a schematic illustration of signal profiles for phase difference measurement.

Identical reference symbols in the figures denote identical elements or elements having the same effect.

Figure 1 shows a longitudinal detail of a telephone line from the start (feed points 11 and 12 for the two individual wires 13 and 14) of the line 10. Without the load coils 15 and 16 inserted in it, the characteristic impedance of the line is Zo.

The load coils in the example are looped-in in series (along the line) in the line at a distance of 2 km from the feed point, and then repeatedly after every 2 km. The coils are designed such that they reduce the line attenuation for frequencies in the speech band up to 3.4 kHz. However, at higher frequencies, the attenuation rises drastically, so that data transmission is impossible with all DSL methods.

It is thus necessary to use methods described here to determine whether an existing line is or is not provided with load coils, in order to determine its suitability for transmission methods which use considerably higher transmission frequencies (for example ISDN, VDSL, SDSL, ADSL).

The methods according to the invention allow such determination of suitability in the sense of the presence or absence of load coils in the line, without any additional test equipment, using solely the existing hardware together with associated software.

Figure 2 shows the equivalent circuit of the line

arrangement shown in Figure 1 for low frequencies, for which the line length as far as the coil (in the example 1 = 2 km) is very much shorter than the wavelength.

For simple estimation purposes, the line elements of the pure wire line can be combined to form concentrated elements, specifically to form a resistor 21 (R'), the coil 22 (L') and the capacitor 23 (C').

The characteristic impedance of the line is changed from Zo to Zc by the incorporation of the load coils. The input impedance is obtained by terminating the equivalent circuit with the characteristic impedance Zc.

Zc takes account of the load coils.

Zc thus has a high resistive and capacitive component for low frequencies, as is shown in the further simplified equivalent circuit as shown in Figure 3 by the switching element 30, which replaces the further line and the coils, with the resistor 31 (Rc) and the capacitor 32 (Cc).

The qualitative profile of the characteristic impedance plotted against the frequency w is shown in Figure 4. The graph shows the real part of Zo 41 and the real part of Zc 43 (that is to say when coils are present), as well as the imaginary part of Zo 42 and of Zc 44. The curves differ noticeably from one another. The difference will become even more clear in the following text. In this case, however, it can be seen that the profile of the input impedance also has "ripples" in comparison to a line without load coils.

Figures 5 to 8 show the influence of constraints at the end 18 of a first line section 13 composed of wire. Three curves are in each case plotted, with a denoting a value profile for a line which is open at the end 18, b denoting a value profile for a line which is connected at the end 18 via a load coil to a further piece of line, and c denoting a value profile of a line which is connected at the end 18, without any coil, directly to a further piece of line.

Figure 5 shows the magnitude of the input impedance of the line at the feed point (11, 12). Figure 6 shows the real part of the input impedance. Figure 7 shows the imaginary part of the input impedance and, finally, Figure 8 shows the phase shift of the input impedance of the line.

As can clearly be seen, the difference can be evaluated in all the values, but is strongest in the phase profile, which appears to suggest that evaluation of the phase profile is preferable.

In this context, Figures 9 and 10 once again show the typical profile of the phase shift of the first derivative (Figure 9) and of the second derivative (Figure 10) in more detail.

The described problem, that is to say the detection of the load coils, is solved by detecting the very different profiles of the characteristic impedances between a line with and without load coils in the lower frequency range (that is to say in the speech band), to be precise using the already existing hardware.

Figure 11 shows the procedure for the analysis part of the method after a test signal in the form of an AC

voltage has been fed into the telephone line and the phase shift of the reflection signal of the test signal has been measured as the measurement signal at a number of different frequencies. For illustrative purposes, Figures 12 to 15 show the processing of the data records, once again with the boundary conditions a, b and c (see above).

The analysis method steps are carried out as follows: Analysis of the profiles of the measurement signals, with the derivative 91 of the profile of the measurement signals based on the frequency being formed (see Figure 12 for a typical data record). The profile measurement signal is then subjected to averaging 92 by forming the median of the individual measurement signals in order to smooth their profile. In this case, by way of example, eight adjacent values may be smoothed jointly (see Figure 13 for a typical data record).

Data reduction 93 is carried out in the step following the median formation, in which only individual smoothed measurement signals, which are separated by regular intervals (for example only every eighth value) are supplied for further evaluation (see Figure 14 for a typical data record).

The second derivative 94 of the profile of the reduced smoothed measurement signals is now produced on the basis of the frequency (see Figure 15 for a typical data record).

All that now need be looked for is a mathematical sign change in the profile of the second derivative (95). These exist in lines which contain load coils, but no mathematical sign changes occur in lines without load

coils. The mathematical sign change can be used to clearly deduce the presence (96) or absence (97) of load coils.

Figure 16 shows a typical DSL module 100, as may be used. This has a sine-wave generator 108, which supplies the signal via a transmission filter 105a and the digital/analog converter 105b to the hybrid 103 (which also contains a line driver). The hybrid 103 is connected directly to a transformer 104, via which the signal is fed into the line 10 on both wires 13 and 14. The DSL module receives signals from the line 10 again via the transformer 104 and the hybrids 103, and supplies the separated signal via an analog/digital converter 106b and a reception filter 106a to the echo compensation device 107. This is normally used to actually separate its own reflected signal.

Some DSL cards 100 also have a line test device 102, as is illustrated in Figure 16. This is able to pass analog signals (which are produced by means of signal generation devices 111 and 112) to the line 10, in order in this way to carry out fundamental functional tests of the line. For this purpose, by way of example, measured values which are dropped across resistors 113 and 114 are evaluated by means of an evaluation apparatus 115. The test may comprise simple resistance tests or the like (metallic loop test).

In order to carry out the method, the AM modulators in the transmission path can be used to produce the sinusoidal measurement signals. The reception path comprises the ADC 106b (analog/digital converter), the downsampling from the ADC sampling rate to the symbol rate, the RX filter 106a and the echo compensation 107. The echo compensation comprises the actual FIR echo

compensator filter 107 and the adder 107a, which, in the data mode, subtracts the echo which is simulated by the echo compensator filter, from the filtered received signal (that is to say switched off in the method). For adaptation, the remaining echo is supplied, downstream from the adder, to the adaptation part of the echo compensator filter. Furthermore, the reception path has an r*4kHz demodulator 107b, by means of which the data can be recovered during the G.hs procedure.

The arrangement of the hybrid and transformer likewise corresponds to the normal application. The transformer winding is split on the loop side, and the winding elements are connected to a capacitor in order to avoid a short circuit during power feeding. In this case, the hybrid should also contain the line driver, which may have an internal resistance Ri.

The method for detection in the transceiver will be described in the following text: transmission of a sine-wave signal. TX and RX filters connected as bandpass filters. Echo compensation switched off, that is to say Ure=Ur. Demodulation of the "echo" and measurement of the amplitude of the demodulated signal.

In all of the measurements, the gain factors during transmission and reception and the internal resistance Ri remain the same. The voltage of the line start and thus also the complex value of the "echo" is obtained from the voltage split between Ri and the complex Zc transformed via the transformer and the hybrid. For lines which have load coils, the profile of the "echo" is different from that on lines which do not have load coils, and the demodulated signal is correspondingly different. It is thus possible to identify the presence of load coils from, for example, the profile of the

demodulated signal.

The input resistance of the loop (line) is thus measured indirectly by measurement of the received signal. The relationship between the received signal and the transmission signal is measured as the transfer function.

The line test device 102 likewise has line drivers which - controlled by "settings" by the HOST - can, for example, pass differential sine-wave tones to the line. The current can be measured at the driver outputs.

The following text describes how the method can be carried out using the test device:

A differential sine-wave signal of constant amplitude is transmitted, and the amplitude of the driver current is measured. This is different in the case of lines with load coils than in the case of lines without such coils, if the frequency is in a range in which the two characteristic impedances differ to a major extent (at low frequencies). It is thus possible to detect load coils.

Both specific methods are based on the assumption that the line is open at the end and is terminated by a telecommunications system which is currently not active, so that the input impedance of the line is not "corrupted" by a terminating impedance (which is generally in the region of 135 ohms).

Figure 17 once again shows the various areas in which the method is carried out. First of all, the hardware which is used in DSL modems - as already described - is used for measurement. The measurement signals 134 and

135 which are tapped off can be evaluated both by software and by special hardware 131. The subsequent evaluation 132 of the analysis results, which finally produces the result "load coils present/not present", is generally in the form of software.

The input resistance of the line can be measured only indirectly with the aid of the modem: in fact, the entire input impedance of the hybrid is always measured. Since the transformer impedance has a very major effect on this, the difference in the magnitudes of the input resistances of the hybrid are only very small between lines with or without load coils. It is very difficult to evaluate the measurement results.

The detection of load coils can thus be carried out, in particular, by measurement of the profile of the phase of the input resistance of the hybrid in the frequency range from 1.5 to 5 kHz, and by determination of the gradients. The measurements could be carried out with a step width of 100 to 200 Hz.

Figure 18 and Figure 19 show two different apparatuses for analysis of the phase profile, that is to say for formation of phase difference measured values over the frequency. In the first variant (Figure 18), the mathematical sign (141, and 142) is in each case formed from the transmission signal 134 and from the received signal 135, which are sinusoidal and have no DC voltage component, and are supplied to a (digital) phase discriminator 143. One specific embodiment relating to this will be described further below (Figures 20 and 21).

The variant in Figure 19 shows a quadrature demodulator 150 for formation of phase difference measured values,

which carries out quadrature demodulation of the received signal, with the transmission signal (test signal) being used as the carrier.

Figure 20 shows one embodiment for phase measurement using the modem hardware and a simple additional circuit. The corresponding signals are shown in Figure 21. The production and TX filtering of the symbols are carried out such that a sinusoidal transmission signal, without any DC voltage component, is produced at frequencies from 1.5 kHz to 5 kHz. Corresponding to the voltage split between the line driver internal resistance and the hybrid input impedance, which includes the input impedance of the line 10, this results in a sinusoidal received signal downstream from the analog/digital converter 106b. If the discrete-amplitude transmission signal and received signal are coded using two's complement form, only the most significant bits (that is to say the mathematical signs 210 and 220, which each have a flank 211, 212 and 221, 222 when the mathematical sign changes) are in each case determined and passed on, by supplying them to an exclusive-NOR gate 133. The output signal 230 with the corresponding flanks 231 and 232 of this gate 133 is filtered by means of a low-pass filter 131, whose cut-off frequency is, for example, 100 Hz. The output signal 240 from the low-pass filter is a measure of the phase difference between the transmission signal and the received signal, and can be written for each measurement to a register 132 which can be read by software. The exclusive-NOR gate and the low-pass filter represent a simple coincidence detector.

List of reference symbols

10	Line
11, 12	Feed points
13, 14	Wires
15, 16	Load coils
17	End of the line
18	End of the line section
Zo, Zc	Characteristic impedance
21	Resistance
22	Coil
23	Capacitor
30	Switching element
31	Resistor
32	Capacitor
41	Real part of Zo
42	Imaginary part of Zo
43	Real part of Zc
44	Imaginary part of Zc
a	Value profile of the open line
b	Value profile of the load coil
c	Value profile of the connected line
91	Derivative of the profile
92	Averaging
93	Data reduction
94	Second derivative of the profile
95	Search for a mathematical sign change
96	Mathematical sign change, yes
97	Mathematical sign change, no
100	DSL module
101	Transceiver
102	Line test device
103	Hybrid
104	Transformer
105a	Transmission filter
105b	Digital/analog converter

106b	Analog/digital converter, ADC
106a	Reception filter, RX filter
107	Echo compensation device
FIR echo compensator filter	
107a	Adder
107b	r*4kHz demodulator
108	Sine-wave generator
111 and 112	Signal generation devices
113 and 114	Resistors
115	Evaluation apparatus
Ri	Internal resistor
134 and 135	Measurement signals
131	Specific hardware, low-pass filter
132	Evaluation, register
133	Gate, exclusive-NOR gate
134	Transmission signal
135	Received signal
141, 142	Mathematical sign formation
143	Phase discriminator
150	Quadrature demodulator
210 and 220	Most significant bits (mathematical sign)
211, 212	Flank
221, 222	Flank and
230	Output signal
231 and 232	Flanks
240	Output signal of the low-pass filter